AIR SERVICE INFORMATION CIRCULAR

(AVIATION)

PUBLISHED BY THE CHIEF OF AIR SERVICE, WASHINGTON, D. C.

Vol. IV May 15, 1922 No. 341

DESCRIPTION OF McCOOK FIELD 5-FOOT WIND TUNNEL

(AIRPLANE SECTION, S. & A. BRANCH)

▽

Prepared by
E. N. Fales, Engineering Division, Air Service
McCook Field, Dayton, Ohio
August 10, 1921

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

Certificate: By direction of the Secretary of War, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

DESCRIPTION OF McCOOK FIELD 5-FOOT WIND TUNNEL.

The new wind tunnel of the Air Service Engineering Division has for object to afford the service more convenient aerodynamic testing facilities than have hitherto been available. The past few years have seen an increase in the amount of this testing, until in 1920 outside contracts amounted to $30,000. In consideration of this annual outlay, and of the inconvenience resulting from such an arrangement, it has been found desirable to erect a new wind tunnel at McCook Field, and construction commenced in June, 1921.

It is not necessary here to discuss the use to which wind tunnels are put further than to state that by their means the designer acquires much of his aerodynamic data. The method involves small-scale models of any desired design, which are subjected to an artificial air blast, and the resulting air forces measured by a balance. The coefficients of "Lift," "Drag," etc., are thus determined, and may be applied to aircraft when suitably corrected for scale effect.

This correction may reach a value such that special requirements are introduced into the design of the wind tunnel. Within certain limits we are led by the law of dynamic similarity to prefer a wind tunnel which will afford the maximum product speed × size. Thus, theoretically, a tunnel large enough to test a full-sized airplane at normal air speed may be replaced by a one-fourth scale tunnel operating at quadruple speed. Practically, we have not yet attained a tunnel greater than one-sixth scale, the more popular size being one-twelfth scale; and if we increase the velocity to correspond we reach air flow régimes where the forces created can not always be interpreted by means of the law of dynamic similarity. Evaluation of the "scale effect" at high velocities is not yet satisfactorily understood, nor will it be until our fund of knowledge of high-speed phenomena is increased. It is thus obvious from aerodynamic considerations that our choice of a wind-tunnel design must be something of a compromise. Furthermore, for the more practical consideration of size and cost of plant, we must again compromise.

If our wind tunnel is to afford the maximum sphere of usefulness, it must therefore be more than a copy of some other existing tunnel, and it must be designed to accommodate the necessary aerodynamic characteristics, together with the conditions imposed by power and expense limits.

COST OF PLANT.

It is not difficult to secure in a moderate-sized wind tunnel the full flight velocity; but velocities sufficient to offset the scale effect are impracticable. The power will vary approximately as the cube of the velocity and the square of the dimension, and from this standpoint large size and slow speed are easier to attain than small size and high speed. But the larger the volume of air handled, the larger must be the building; for the air exhausted from the tunnel, recirculating through the building toward the intake, must there have small entrance velocity; and this requires that the building have large height and width The cost of such a building varies with the cube of diameter and with the first power of the velocity; hence from consideration of space available, the small high velocity wind tunnel is preferable.

DETERMINING OF CHARACTERISTICS OF THE McCOOK FIELD 5-FOOT WIND TUNNEL.

For the Army Air Service a desirable combination is an 8-foot diameter tunnel having a velocity equivalent to that of a full-sized airplane, say, 150 miles per hour. For practical reasons (at the date of the order of the present wind tunnel project, no building was available on McCook Field large enough for an 8-foot tunnel) a smaller diameter, 5 feet, was chosen as the maximum in which reasonable smoothness of air flow at conventional speeds could be expected. In such a tunnel fairly high velocity may be obtained for special work, such, for example, as problems in propeller design. Due to uncertainty of future location, portability is an advantage favoring the smaller size. In the entire design provision is made such that the plant can be moved in the future and increased in size when moved to its permanent location.

POWER PLANT.

The design of the wind tunnel has been arranged to utilize electric motors already available, and no outside purchase has been necessary beyond the motor-generator equipment. Each of the two fans is driven by two Sprague dynamometers, which were reserved from the Liberty engine production equipment. The result is that economy of first cost is combined with efficiency of operation.

POWER ECONOMY.

Where large power is involved as in the case of a high speed wind tunnel it is important to apply to the design all available considerations of power economy. The most important item has to do with the air flow in the tunnel downstream of the model; that is, in the cone and through the fan. It is of interest to mention here the considerations determining the design of such a cone.

DECELERATING CONE.

The decelerating cone, which is so important in a high-speed wind tunnel, is familiar to the ventilating engineer and hydraulic engineer in commercial application; it is found in ventilating circuits under the term of "blower chimney" and in hydraulic power plants under the name of "draft tube." It is also used in the Venturi tube flow meter for measuring flow of water in pipes. According to the Bernouilli theorem, such a cone facilitates interchange of the pressure and velocity energies of the fluid passing through it; for the fluid, changing its velocity in proportion as it traverses the varying areas of cross section of such a

100300—22——1

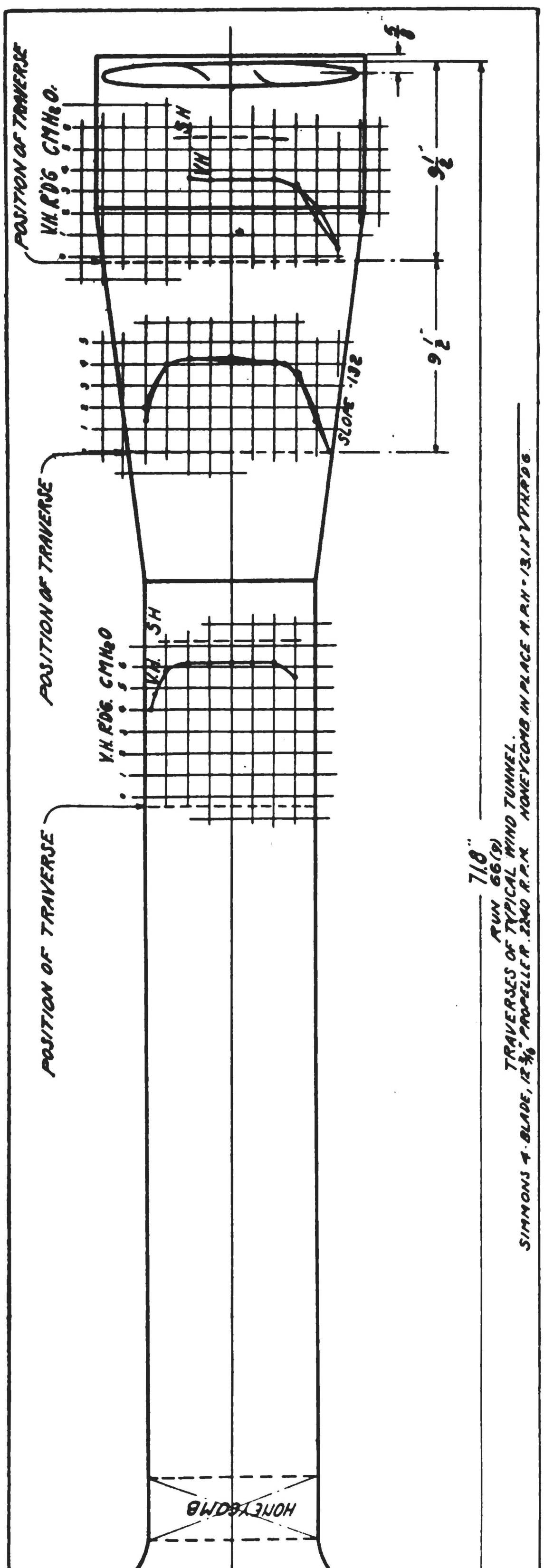

FIG. 1—Air flow, in wide angle cone, traverses of typical wind tunnel.

cone, also undergoes a change of pressure at each successive point. In a properly designed decelerating cone the total energy of air moving toward the large end may be within 10 per cent of its value at the small end.

No thorough analysis of the aerodynamic characteristics of this interchange of energy has been perfected, but we may obtain a very good idea of the nature of the flow distribution by means of experiments, such as have been developed in the Air Service, made either on model or full-scale wind tunnels. Figure 1 shows the velocity distribution in a 15° cone fixed to an 8-inch model wind tunnel; the boundary of the undisturbed air flow does not extend to the cone walls, but is separated from them by an annular space of reduced pressure. In figure 1 the cone angle is too great. Figure 2 shows the distribution of dynamic pressure in the McCook Field 14-inch wind tunnel. The space is occupied by flowing air whose velocity and energy is less than the corresponding value within the central core, the equivalent loss of pressure being greater at points successively nearer to the walls of the cone. Figure 3 shows the longitudinal pressure gradient in the 14-inch tunnel.

Evidence has been found that air, when decelerating, will maintain an expansion angle somewhat smaller than the angle which has been proved best for these cones. Particular evidence of the formation of the "virtual" cone was found in the model wind tunnel tests made in connection with the design of the McCook Field high-speed wind tunnel, and may also be observed by reference to tests shown in figure 2. For a rough visualization of the nature of the air flow within the decelerating cone, we arrive at the best conception if we imagine the flow shape to be that of a "virtual" cone, the walls surrounding it being simply a barrier to prevent inflow of outside atmospheric air.

Figure 4 is a chart showing the degree of energy interchange to be expected from cones of varying length. We observe that but small profit in energy recovery follows from increasing the large diameter to a value greater than two and one-half times the small diameter.

GENERAL DESCRIPTION OF McCOOK FIELD 5-FOOT WIND TUNNEL.

The foregoing analysis of cone functioning has been emphasized because of its major importance and is fundamental in the successful design of a high-speed plant. The other parts of the wind tunnel are similarly subject to analysis; the cylindrical portion, the intake bell, the blades or vanes for straightening the air flow, the honeycomb, and the "return flow equalizers," etc., are other technical items which are of importance in producing smooth air flow in the wind tunnel. These will not be discussed here.

GENERAL SHAPE.

Figure 5 shows the wind tunnel in cross section, located in a standard steel hangar. From the dimensions and constructions there shown, the reader will observe that several processes have been evolved tending toward economy of construction and operation. The center line of the wind tunnel is elevated above the floor an amount such that the return flow area above and below bear the proper relation to each other. Several of the roof trusses are raised in order to accommodate the wind tunnel struc-

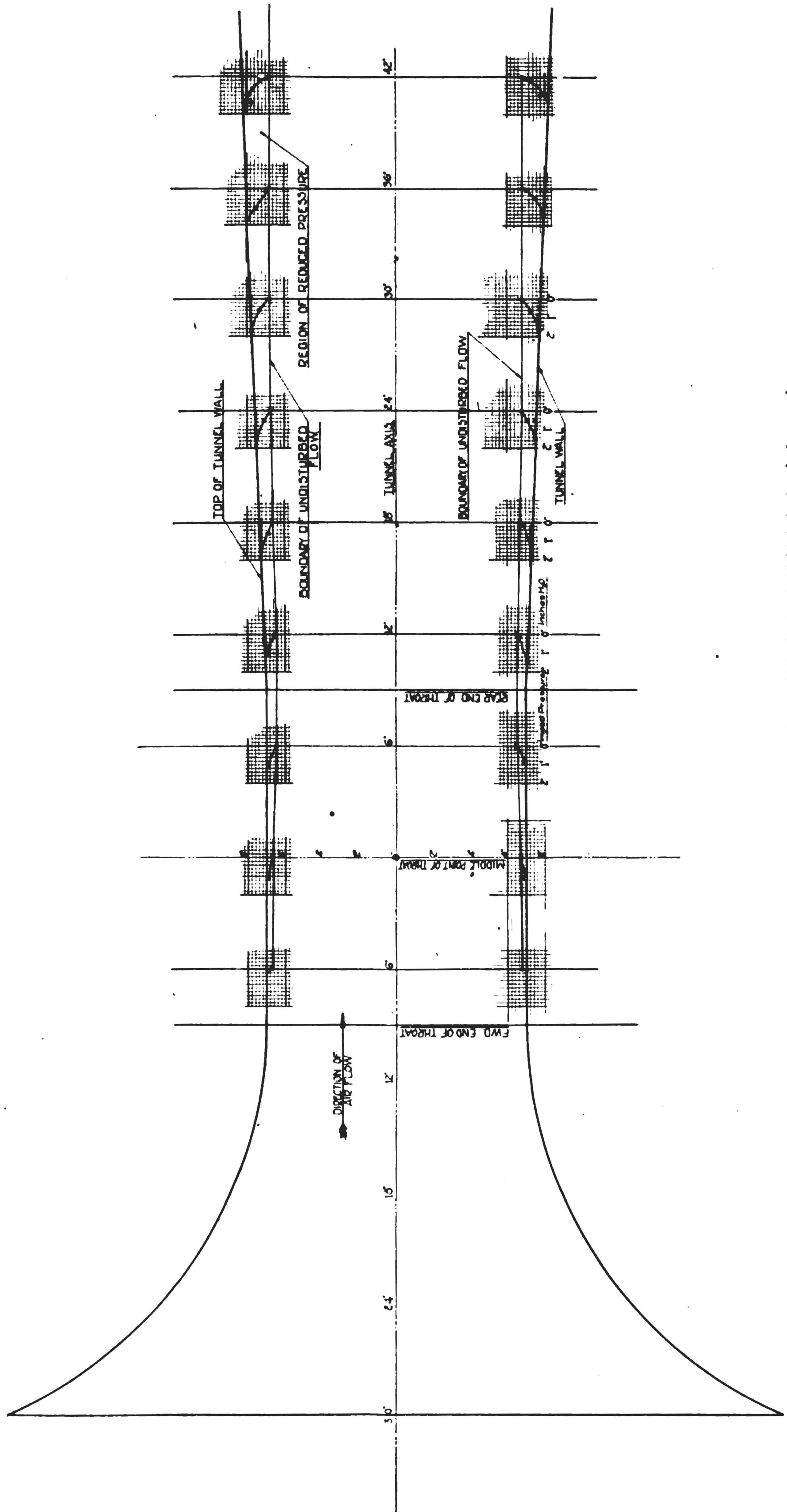

FIG. 2.—Longitudinal and lateral traverse of dynamic heads in McCook Field 14-inch wind tunnel.

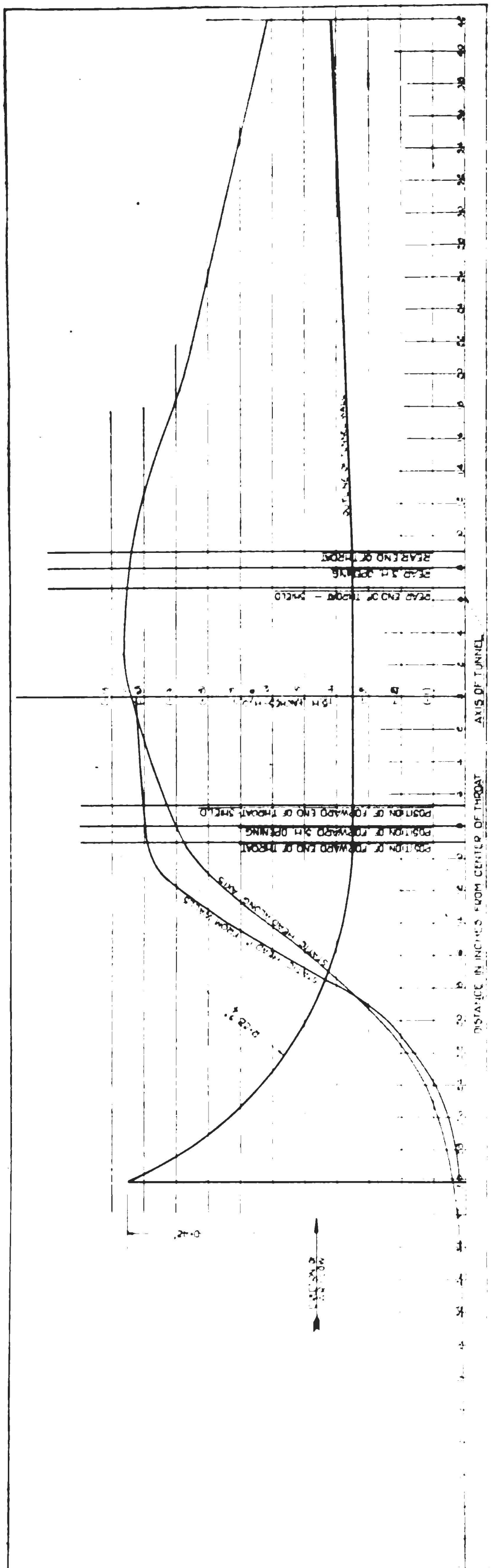

Fig. 3.—Longitudinal traverse of static heads.

ture; the horizontal stringer is removed and replaced by a post and knee brace. The proportions of the hangar, with low roof and wide span, offer poor accommodation for proper return flow uniformity of the air. Furthermore, this type of hangar is not impervious to entrance of atmospheric pressure changes due to wind gusts, and special precautions are therefore requisite.

FOUNDATIONS.

Foundations for the fan motors are set in the north end of the hangar. The balance foundation is located approximately 40 feet from the south end. No foundations have been thought necessary for the tubular wooden structure, whose weight is adequately taken up by the heavy concrete floor installed in the hangar.

EXPERIMENTAL PORTION.

The cylindrical portion of the tunnel consists of a 12-foot and a 6-foot section, either or both of which may be used. The flanged joints are drilled to templates in such a way that various sections are interchangeable. A carefully aligned rail carries this cylindrical portion, which can be rolled in or out as desired and set in proper alignment. Provision has been made for removing such members of the supporting framework as conflict during its movement with the balance foundation.

METHOD OF CONSTRUCTING THE TUBE AND CONE.

The method of construction adopted is thought to be an improvement over previous methods, embodying the advantage of a tubular column. Narrow staves of seasoned Port Arthur cedar were cut in a four-side molder with the tongue-and-groove joint principle. These were placed together inside circumferential rings, and glued and screwed to each other, each section of the tunnel thus being a rigid unit. For the cylindrical portion, the rings were glued up out of segments to a thickness of about 4 inches and a depth of about 6 inches. To make the individual curved segments large square boards were first glued up and the curved segments cut out in such a fashion that the inner curvature of one was in juxtaposition with the outer curvature of the next, thus effecting economy of material. In gluing up the rings screws were used rather than clamps.

TURNING THE RINGS.

The smaller rings were turned on an overhung lathe. The flat sides were turned and the curved surfaces were cut in a special shaper, using a turned template. The larger rings for the cone were similarly shaped in an Oliver woodworking machine, rotating on a vertical axis under a rotary cutter having adjustable head, the latter being swung to cut the proper angle, whether for the cylindrical portion, which was 90°, or the conical portion which was 86½° and 82½°. (See Fig. 6.)

SUPPORTING FRAMEWORK.

The tubular portion, having been completed as a self-sustained unit, is supported by means of cradles under each alternate ring. Each cradle consists of a curved sheet-steel ledge supported by battered legs reaching

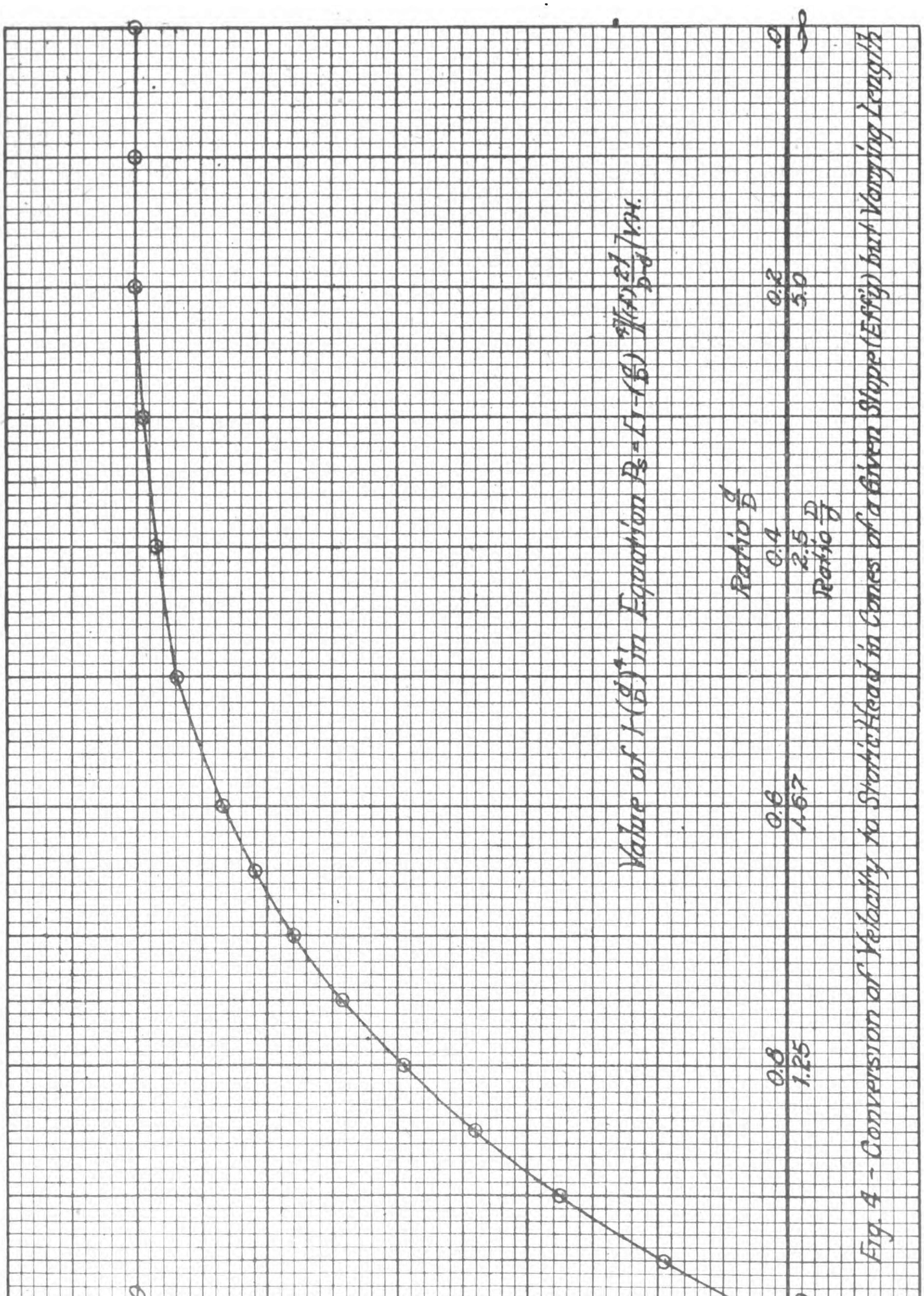
Ratio d/D
Ratio D/d
0
0.2
5.0
0.4
2.5
0.6
1.67
0.8
1.25
1.0
1.0
.2
.4
.6
.8
1.0
Fig. 4 - Conversion of Velocity to Static Head in Cones of a Given Slope (Eff'y) but Varying Length

FIG. 4.

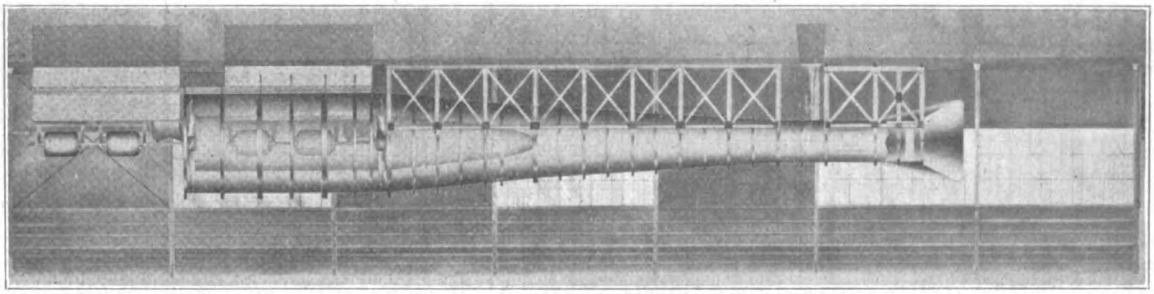

FIG. 5.—Outline diagram of 5-foot wind tunnel.

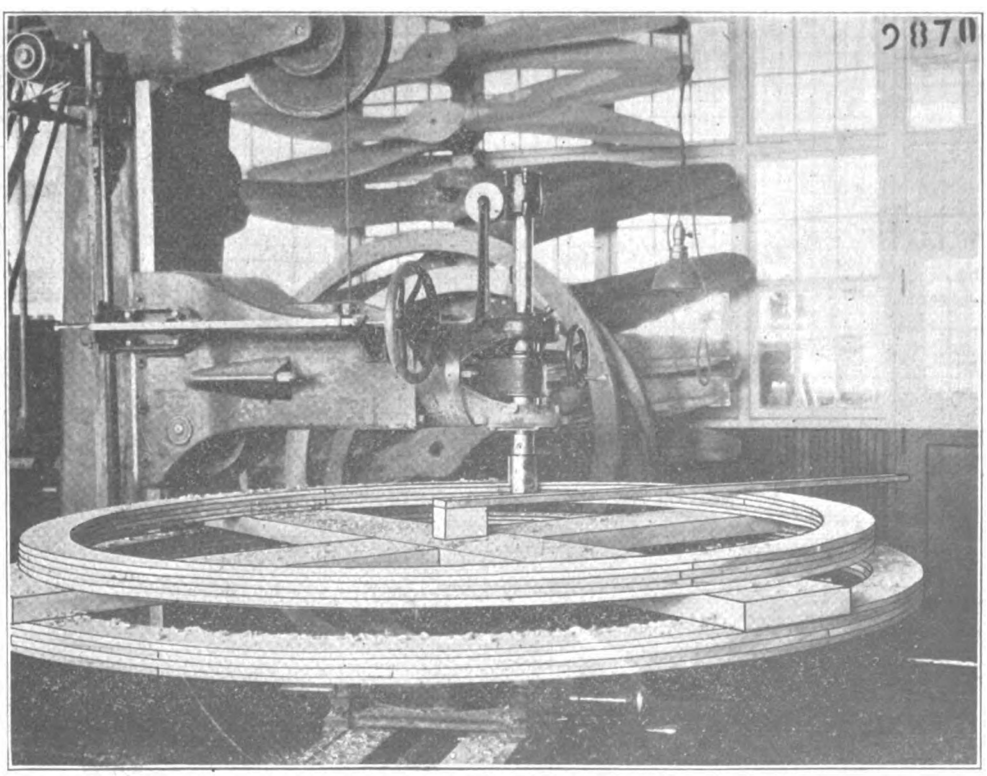

FIG. 6 - Turning large wind tunnel rings on Oliver woodworking machine.

to the floor and properly trussed. The top of the framework receives steel straps which pass above and below the ring for the purpose of anchoring the same to the framework.

PORTABLE FEATURES.

In order to accommodate tests of maximum range and to make use of either of the two balances provided, the cylindrical portions, with their supporting framework, are mounted on wheels, and when not anchored they can roll along small rails set on the concrete floor. Thus any desired combination of experimental chambers may be brought into action.

BALANCES.

Two balances are provided for the wind tunnel. For low speed the NPL type balance is used in order to preserve continuity with earlier testing for the Air Service wherein this type of balance was used. For high speeds a balance of the Wright type will be utilized on the principle shown in figure 8. The NPL balance being of a conventional type need not be described, but the Wright balance introduces new features. It is fastened to the tunnel itself, which is made of cast iron at this point. There is a linkage mechanism above and below the cast-iron tube, and each end of a vertically placed model is thus supported in separate linkages; these linkages move in unison. The advantages of the Wright type balance are that it eliminates velocity fluctuations, which are, of course, the worst factor with which we have to deal in wind-tunnel operation. Incidental virtues are that it enables the operator to read directly the ratio lift over drag; also that it enables the operator to reverse the model conveniently for check tests. The Wright type balance has not previously been used for high-power work, its special scope having been for precision tests in Mr. Wright's laboratory. Its application to the large high-speed wind tunnel is a development which has required considerable change from the original design.

PROPELLERS.

The propeller system, while new as applied to wind tunnels, is one which is dictated by considerations of the entire problem. It is known that the character of the air flow depends somewhat upon the uniformity of pressure traverse at the fan end of the cone. It is also known that if the traverse is not uniform, power losses may occur. For both reasons it becomes essential that a wind-tunnel fan have a unit thrust which is as nearly as possible identical at all portions of the propeller disk. We are at once led by these considerations to the conclusion that the linear velocity of the fan blade elements must not be of wide range, and, therefore, that we must blank off a considerable hub diameter.

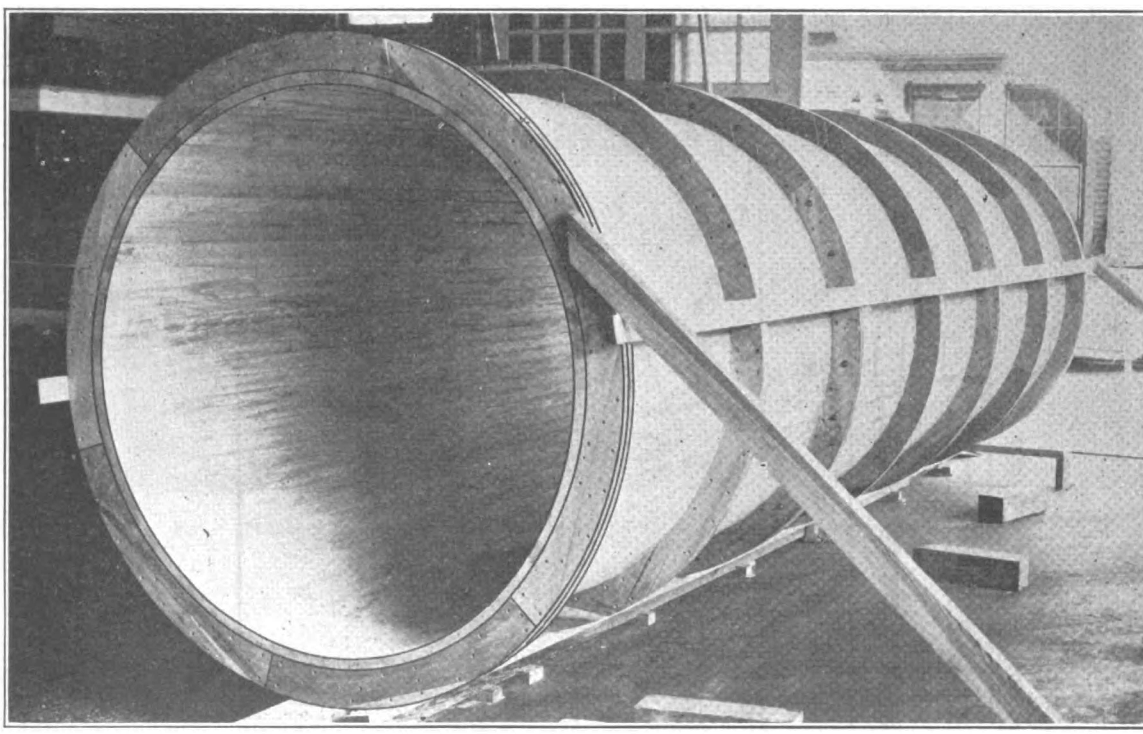

FIG. 7.—Built-up section of cylindrical portion of 5-foot wind tunnel.

In the McCook Field design the fans have a diameter of 11 feet 11 inches, with a hub diameter of 8 feet 8 inches. Corresponding to the blanked-off hub is a core which extends cylindrically between the fans and tapers off upstream. The air passageway in the annular space thus provided has a constantly increasing area, so that the air flow reaches its minimum velocity just before entering the first fan. The air after passing the second fan escapes into the room.

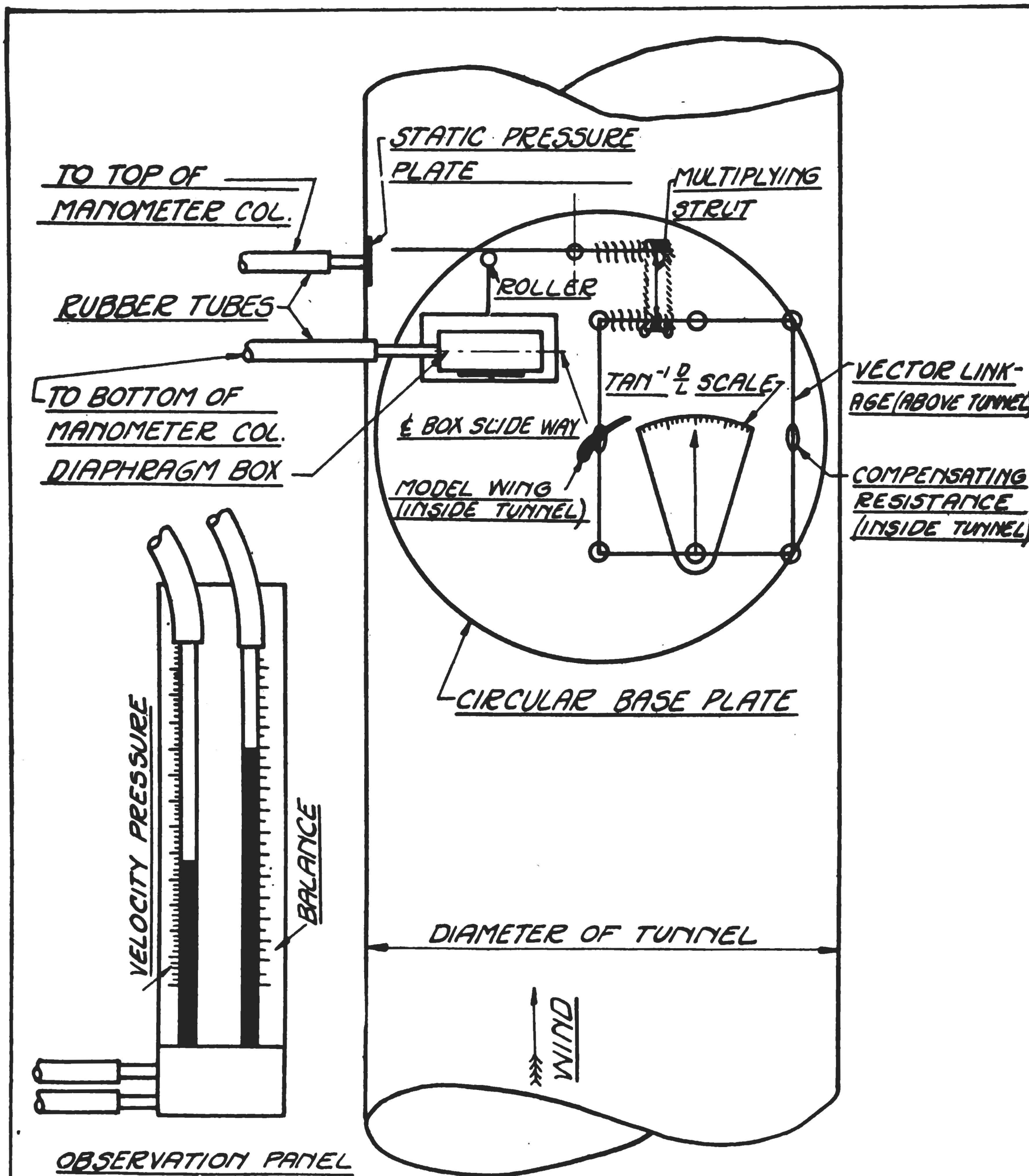

FIG. 8.—Diagram showing principle of operation of Wright type Ventor balance.

TANDEM FAN ARRANGEMENT.

The fans have been designed with the purpose of effecting a suitable compromise between the motive power, the diameter, and the revolutions per minute available for the project; they rotate in opposite directions, absorbing together over 600 horsepower at 900 revolutions per minute, and producing a throat velocity exceeding 200 revolutions per minute.

MEASUREMENT OF VELOCITY.

Measurement of velocity is determined in the conventional manner by means of a flat plate orifice. For determination of the calibration and also for the determination of the pressure gradient along the axis, it is essential to make a longitudinal as well as a traverse map of the air pressures. By means of such traverses, we have found that a very good analysis of the air flow in any wind tunnel can be secured. For calibrating the various manometers on which pressures are read, two gauges are employed—one, the familiar Chattock micromanometer, the other an improvement on the Chattock, by name the Wahlen gauge.

WIND-TUNNEL SCOPE.

From the foregoing it is clear that the design of this tunnel combines features usually not available in a single tunnel. The feature of portability brings it about that the same tunnel may be used for high as well as low speed work. In routine model tests the lower speeds will be used and a honeycomb of the conventional type will be inserted at the throat in order to give the same air flow characteristics as have obtained in Air Service tests previously made by contract elsewhere. For high-speed work the Wright balance will be used.

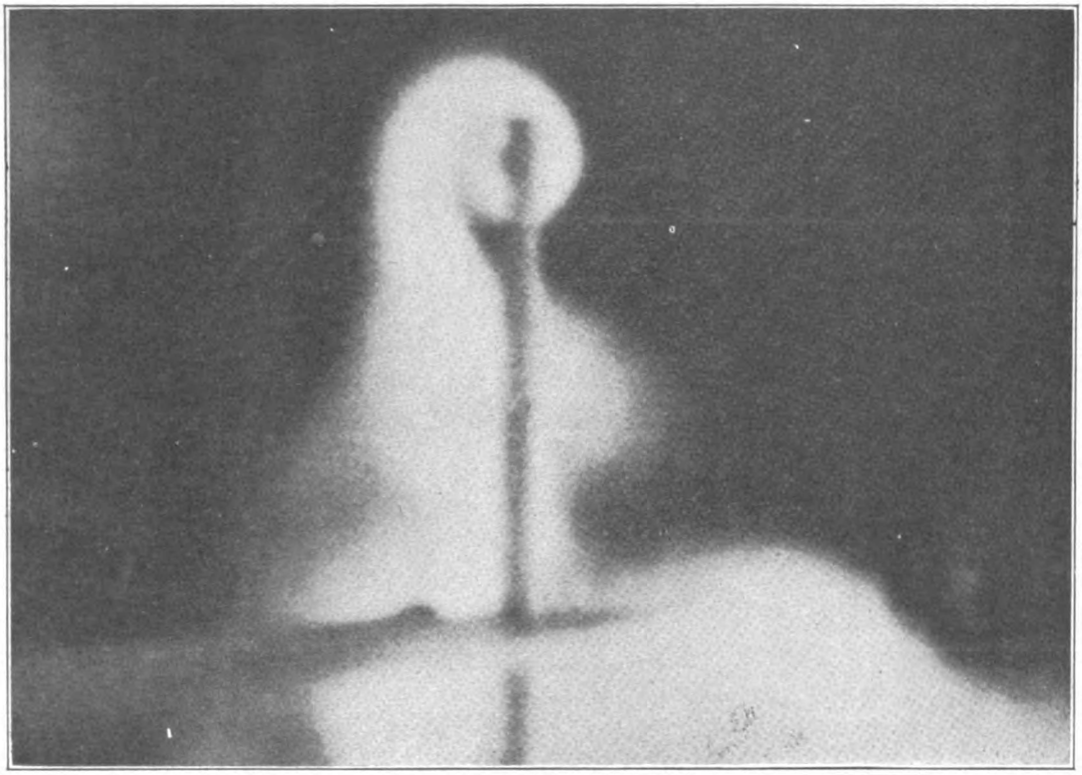

FIG. 9.—Plan view showing tip vortices trailing behind airplane wing, as visualized on model airfoil in high-speed wind tunnel.

HIGH-SPEED RESEARCH.

The new tunnel, while not large, offers a wider speed range than is usual. As a result it is expected that, in addition to routine tests, data will be secured on the speed and scale effects so important to the aircraft designer. The significance of a high-speed range has been demonstrated in the 14-inch tunnel built in 1918, using models the same size as the original models tested by the Wright brothers in 1901. The photograph of figure 9 is illustrative of the 1918 work and shows the character of air flow existing at critical velocity.